NASA TECH BRIEF

Study to Minimize Hydrogen Embrittlement of Ultrahigh-Strength Steels

Atomic hydrogen is capable of entering steel and many other metals and alloys; when it does, any of several undesirable phenomena can occur. If large quantities of hydrogen are introduced, there may be a general loss in ductility or, if the hydrogen accumulates in certain localized areas, internal bursts or blisters may be produced. At elevated temperatures, hydrogen may react with and remove so much carbon from the steel that the material is no longer capable of supporting the design stresses. Under certain circumstances, hydrogen introduced into steel during its manufacture, subsequent fabrication, or in service may result in brittle failures at applied stresses far below the yield strength or the nominal design stress for the alloy. All of these phenomena are collectively referred to as hydrogen embrittlement. However, only the last, i.e., the catastrophic, hydrogen-induced, brittle failure of ultrahigh-strength structural steels at relatively low applied stresses is of interest in the present study. Since this phenomenon frequently occurs in materials that exhibit no appreciable loss in ductility (as measured by a conventional tensile test), it is often termed hydrogen-induced, delayed brittle failure, or hydrogen-stress cracking.

Several conditions must be satisfied for hydrogen-stress cracking of steels to occur:

(1) The steel must be processed to a strength level above some as yet not clearly defined minimum; generally, as the strength level of the steel is increased above this minimum, the time for failure decreases.

(2) The steel must be subjected to an applied tensile stress above some minimum value that is dependent on the strength level of the steel; as the strength level of the steel increases, the minimum applied stress that will result in hydrogen-stress cracking decreases.

(3) The steel must contain hydrogen in excess of some minimum amount, and this hydrogen must be free to diffuse through the steel.

In view of these conditions, it would be expected that any condition that alters the strength, applied stress, or hydrogen content of a given material could influence its sensitivity to hydrogen-stress cracking. The trend toward higher tensile strengths, higher design stresses, and the use of materials in applications requiring prolonged exposure to high sustained loads insures that two of the conditions necessary for the occurrence of hydrogen-stress cracking will be present in steel parts intended for certain aerospace and aircraft applications. All that remains is for an adequate supply of hydrogen to be available and for this hydrogen to be free to diffuse through the steel. Thus, it appears that, for high-strength steels sensitive to hydrogen-stress cracking, the most important factors tending to promote hydrogen-stress cracking under these conditions are the hydrogen content of the material and the propensity of the material to absorb hydrogen from its environment, either during processing or in service.

The problem of hydrogen-stress cracking of ultrahigh-strength steels has become quite serious in the aerospace and aircraft industries because many of the components fabricated from these high-strength steels have to be protected from corrosion in their service environments. The preferred method of providing this protection is cadmium electroplating. However, the application of electrodeposited coatings to solve corrosion problems can make the part susceptible to failure by hydrogen-stress cracking because, frequently hydrogen is introduced during the cleaning and electroplating operation.

Earlier studies showed that most ultrahigh-strength steels were embrittled to various degrees by virtually

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all of the common electroplating processes, including cadmium, chromium, zinc, tin, nickel, lead, copper, and silver. These studies also showed that the amount of hydrogen entering steel specimens during certain electroplating processes may be as great as that introduced during severe cathodic charging, and that more hydrogen sometimes was introduced during pickling or cathodic cleaning prior to electroplating than during the actual plating operation. In addition, these studies showed that the sustained-load tensile test employing notched bars was the most sensitive method for evaluating the embrittling tendencies of cleaning and electroplating processes.

The results of a literature and industrial survey of reportedly low-hydrogen-embrittling and nonhydrogen-embrittling cleaning, pickling, and electroplating processes (including cadmium, chromium, and nickel electroplating) and of various hydrogen-embrittlement relief treatments are described in: "A Review of the Literature on Cleaning, Pickling, and Electroplating Processes and Relief Treatments To Minimize Hydrogen Embrittlement of Ultrahigh-Strength Steels," by T. P. Groeneveld, E. E. Fletcher, and A. R. Elsea, October 15, 1965, Batelle Memorial Institute.

Note:

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